AD-A249 794

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
14 February 1992

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Numerical Simulations of Light Scattering from Rough One-Dimensional Gold Surfaces

5. FUNDING NUMBERS
ARO MIPR 153-91

6. AUTHOR(S)
Eric I. Thorsos

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Applied Physics Laboratory
University of Washington
Seattle, WA 98105

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U. S. Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARO 29288.1-GS

11. SUPPLEMENTARY NOTES
The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
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12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

During 1991 Kevin O'Donnell at Georgia Tech made new measurements of light scattering from gold surfaces, which were well characterized and known to be nearly one-dimensional (1-D). In anticipation of these new data, numerical simulations of the scattering experiments were undertaken in this project for comparison with the data and with results of other investigators.

14. SUBJECT TERMS
Light scattering from rough surfaces, backscattering enhancement, numerical simulation of scattering

15. NUMBER OF PAGES
13

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NUMERICAL SIMULATIONS OF LIGHT SCATTERING FROM ROUGH ONE-DIMENSIONAL GOLD SURFACES

FINAL REPORT

ERIC I. THORSOS

APPLIED PHYSICS LABORATORY
UNIVERSITY OF WASHINGTON
SEATTLE, WA 98105

14 FEBRUARY 1992

Funded by

U.S. ARMY RESEARCH OFFICE

under contract

N00039-91-C-0072

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I. Problem Statement

At the International Workshop on "Modern Analysis of Scattering Phenomena" (held in Aix en Provence, France in September 1990) differences between experimental and numerical scattering cross sections for light scattering from 1-D gold surfaces were reported by Dainty et al. (Imperial College, London). During 1991 Kevin O'Donnell at Georgia Tech made new measurements of light scattering from gold surfaces, which were much better characterized and known to be much more nearly one-dimensional (1-D). In anticipation of these new data, numerical simulations of the scattering experiments were undertaken in this project for comparison with the data and with results of other investigators.

The gold surfaces were assumed to be 1-D and randomly rough with Gaussian statistics. The roughness spectrum was taken as Gaussian with an rms surface height fluctuation of 1.95 micrometers and a correlation length (1/e length) of 3.57 micrometers. Calculations were done at wavelengths of 1.152 and 3.392 micrometers for both "s" and "p" polarizations, and at incident angles of 0, 10, and 30 degrees. Complex refractive indices for gold, 0.312 + 7.93i at 1.127 micrometers and 1.958 + 20.7i at 3.35 micrometers, were used for the wavelengths 1.152 and 3.392 micrometers, respectively. Gold is a good conductor and the accuracy of using the perfect conductor approximation was also investigated.

II. Summary of Results

Integral equation codes were implemented for both s and p polarization following Maradudin et al.[1] Initial test calculations for p polarization showed *significant dependence on* the fineness of the surface partitioning. At the wavelength of 3.392 micrometers, 40 partitions per wavelength were found necessary to obtain reasonable results using the method directly as outlined in Ref.1, whereas to be practical no more than about 10 points per wavelength can be used. The problem was traced to rapid variations of the integral equation kernel due to the complex index in the conductor. In particular, diagonal matrix elements for the second of the two coupled integral equations cannot be computed by the usual small argument expansion keeping only a few terms. However, numerical studies showed that the surface fields could still be considered constant over the partition interval Δx. Thus, we used numerical integration of the kernel over Δx to compute diagonal matrix elements for the second equation. With this method, a partition of 10 points per (vacuum) wavelength was at least as accurate as 40 points per wavelength using the method from Ref.1. The same difficulty could affect the s polarization calculations, but numerical results showed direct use of the method given in Ref. 1 to be adequate for s polarization.

For the calculations, a tapered plane wave incident field[2] was used (taper parameter $g = L/4$ where L = total surface length). The cross section was normalized so that the integral over all scattering angles yields unity for perfect conductors. The number of surface partitions was 400 and the cross sections were obtained by averaging over results for 500 surfaces for each case studied.

The accuracy of the perfect conductor approximation was examined first. When the gold surface is considered a good conductor, the integral equation solution is obtained using coupled equations for two media. When considered a perfect conductor, the integral equation solution is found using Dirichlet (for s polarization) or Neumann (for p polarization) boundary conditions. For s polarization, the perfect conductor approximation was found to be very good (Figure 1). It was found that the good conductor scattering cross sections could be very accurately estimated from perfect conductor results by first calculating cross sections both ways for a 50 surface set, obtaining the cross section ratio for each scattering angle, and then using this ratio to correct other perfect conducting results (with the same incident angle, etc.). Fig. 2 shows estimated and actual good conductor results for one 50 surface set, the estimate based on perfect conductor results corrected using another 50 surface set. The 500 surface results for s polarization were obtained in this way. For each wavelength and incident angle, the cross section ratio was found using 50 surfaces. Then 500 surface perfect conductor results were corrected using the ratio. A considerable computer time saving is made using this method. For p polarization the perfect conductor model was not as good an approximation (Fig. 3) and the full two media calculations were done.

Cross section plots for the two polarizations, two wavelengths (1.152 and 3.392 micrometers), and three incidence angles (0, 10 and 30 degrees) are given in Figs. 4-15. These results were presented at a workshop on backscattering enhancement on January 9-10 in Boulder, CO sponsored by ARO. The results in Figs. 4-15 agreed very well those of several other investigators.

In order to facilitate comparison with experimental data which tends to be smoother than computer simulations with 500 realizations, an attempt was also made to smooth the results. Running least square fits to cubic polynomials were used to generate smoothed cross sections. An example of smoothed and unsmoothed results is shown in Fig. 16. The smoothing was not applied near the backscattering enhancement peak. Plots of smoothed results as well as tabulations of both smoothed and unsmoothed cross sections were made and are available.

References

1. A.A. Maradudin, T. Michel, A.R. McGurn, and E.R. Mendez, Enhanced Backscattering of Light from a Random Grating, Annals of Physics **203**, 255-307 (1990).

2. E.I. Thorsos, The Validity of the Kirchhoff Approximation for Rough Surface Scattering Using a Gaussian Roughness Spectrum, J. Acoust. Soc. Am. **83**, 78-92 (1988).

III. Participating Scientific Personnel

Eric I. Thorsos, PI

Patricia A. Oakley

Kate M. Bader

All participating personnel are at the Applied Physics Laboratory, University of Washington, Seattle, WA 98105

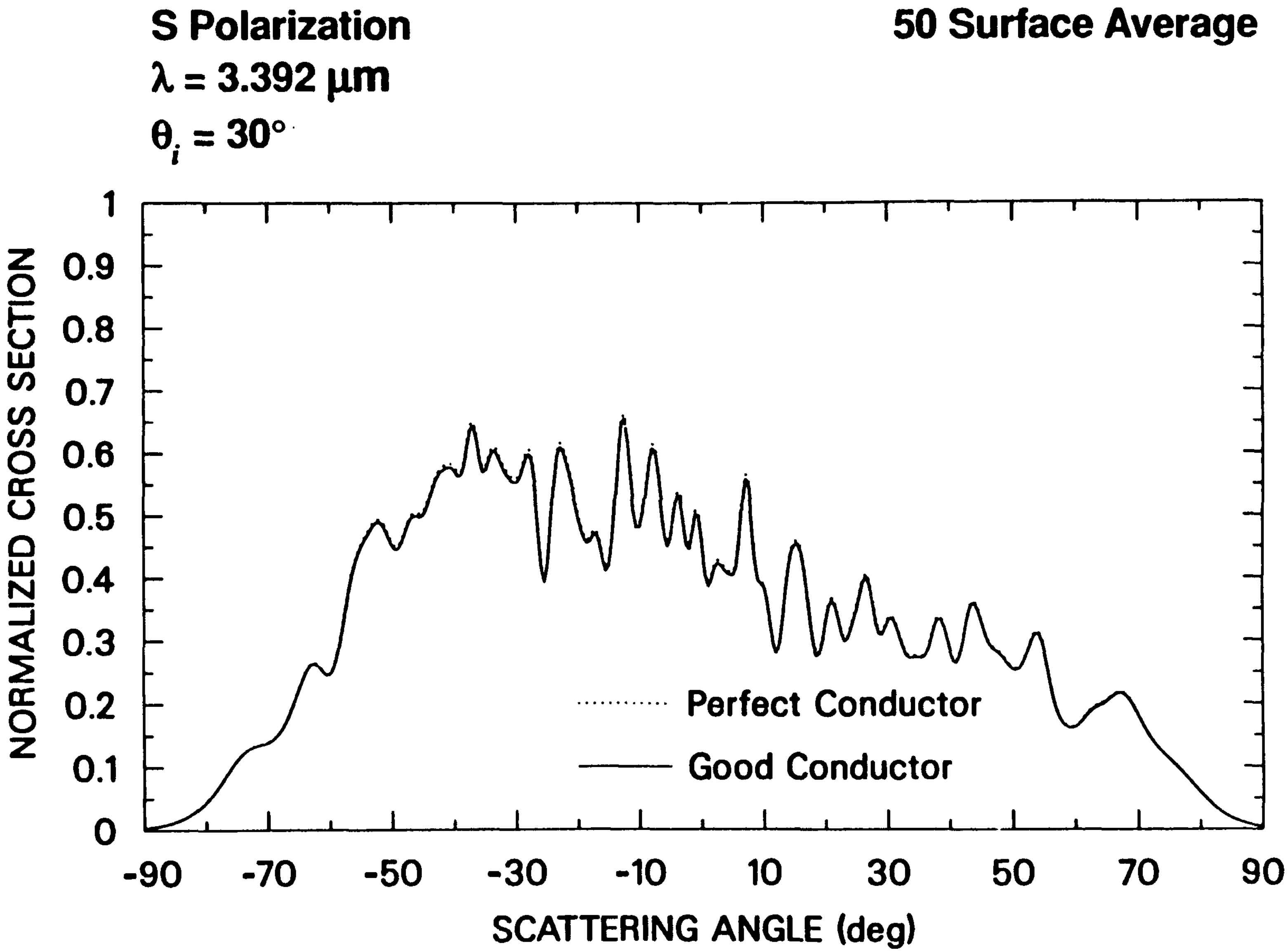
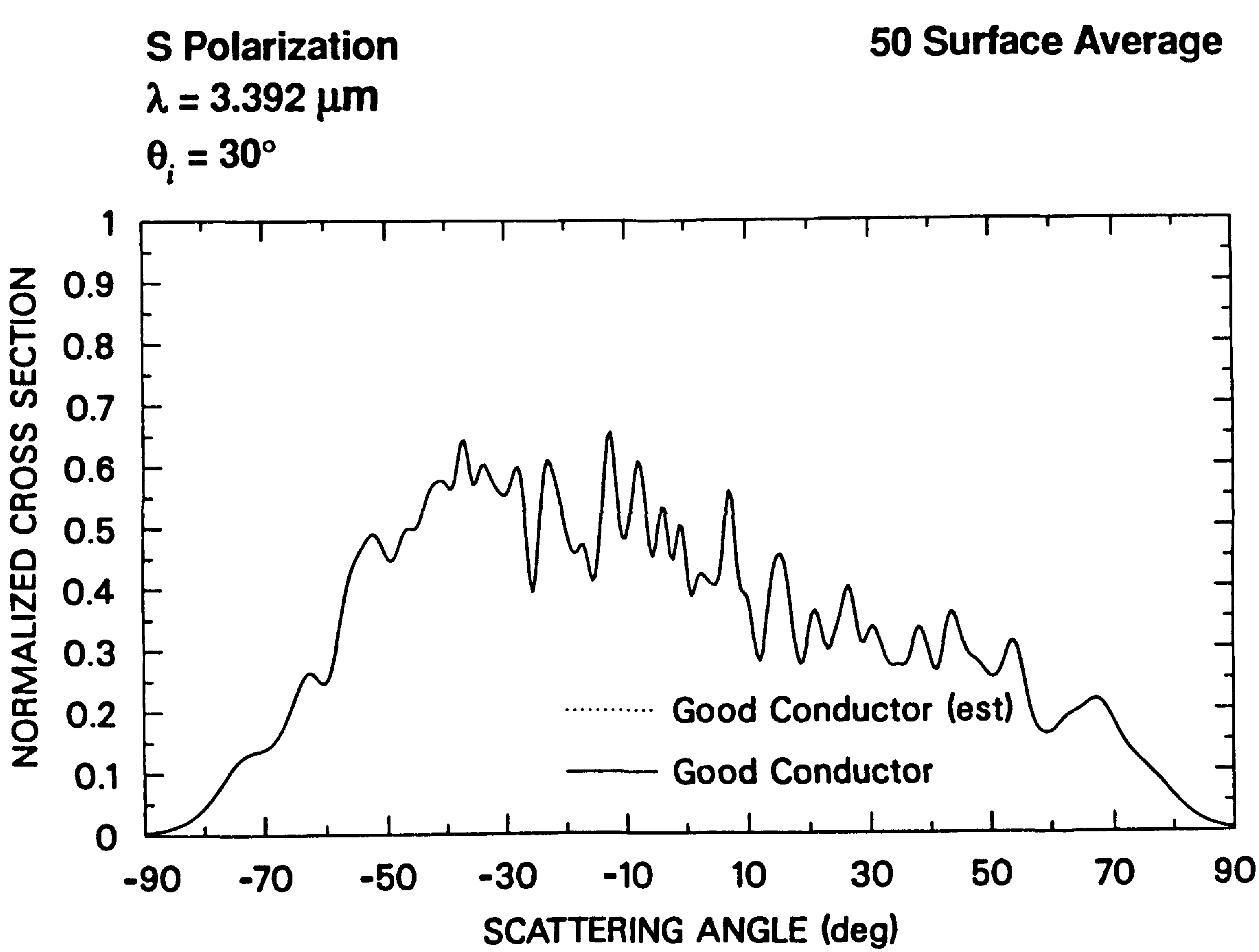

S Polarization
λ = 3.392 μm
θi = 30°
50 Surface Average
NORMALIZED CROSS SECTION
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Perfect Conductor
Good Conductor
-90
-70
-50
-30
-10
10
30
50
70
90
SCATTERING ANGLE (deg)

Figure 1.


S Polarization
λ = 3.392 μm
θi = 30°
50 Surface Average
NORMALIZED CROSS SECTION
0
0.1
0.2
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0.4
0.5
0.6
0.7
0.8
0.9
1
-90
-70
-50
-30
-10
10
30
50
70
90
SCATTERING ANGLE (deg)
Good Conductor (est)
Good Conductor

Figure 2.

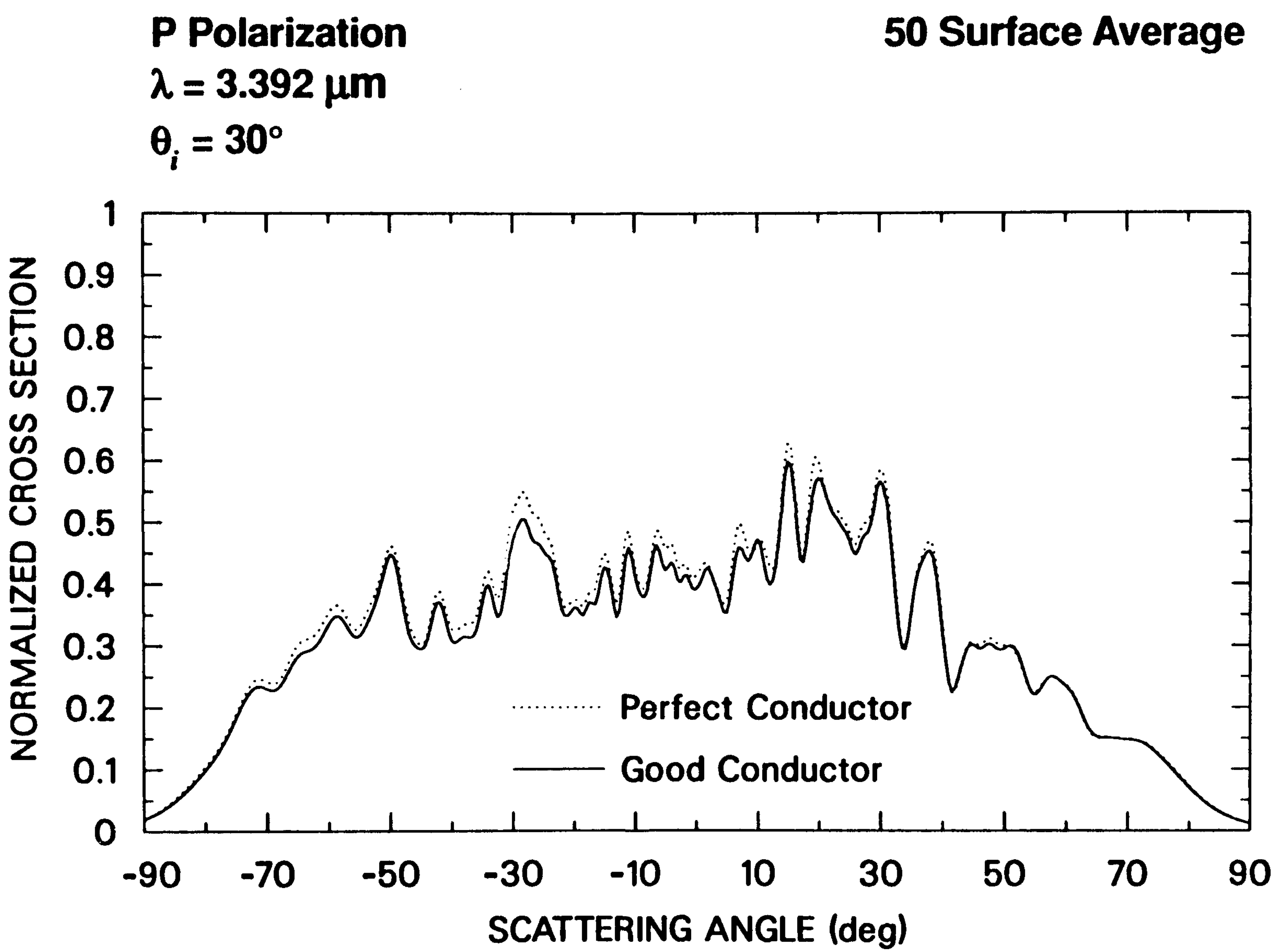
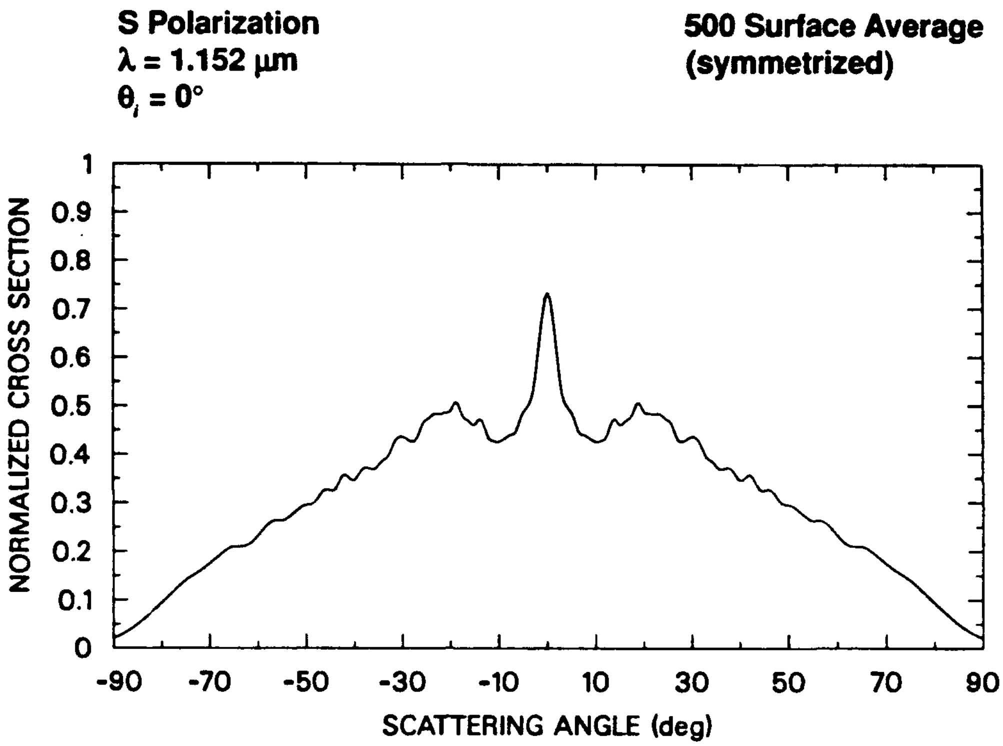

P Polarization
λ = 3.392 μm
θi = 30°
50 Surface Average
NORMALIZED CROSS SECTION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-90
-70
-50
-30
-10
10
30
50
70
90
SCATTERING ANGLE (deg)
Perfect Conductor
Good Conductor

Figure 3.



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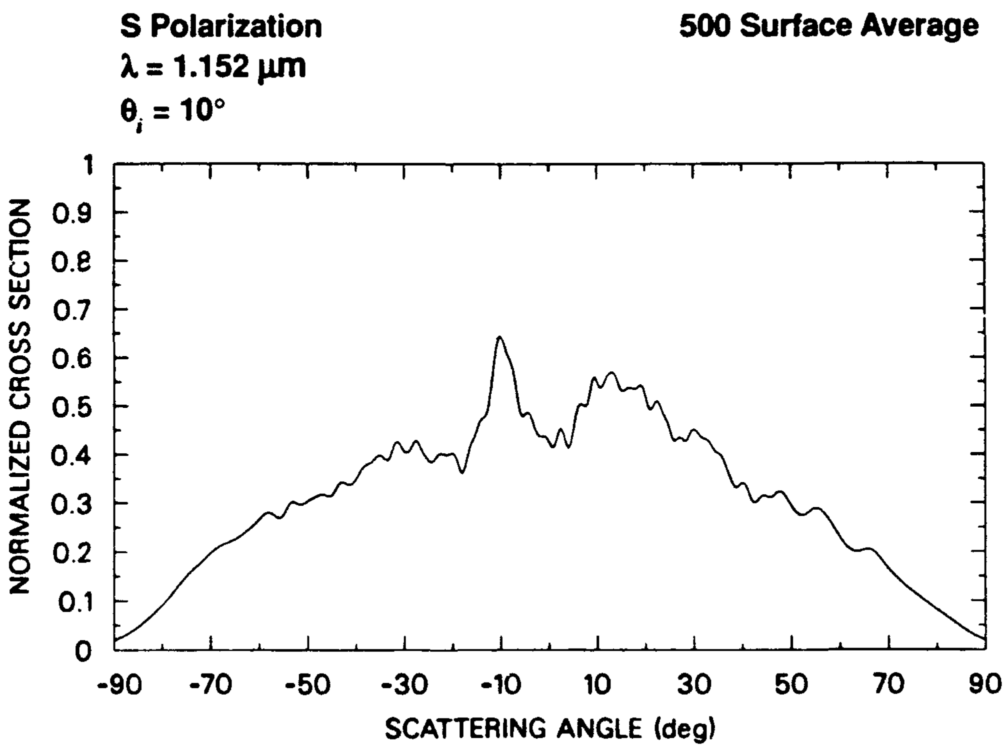

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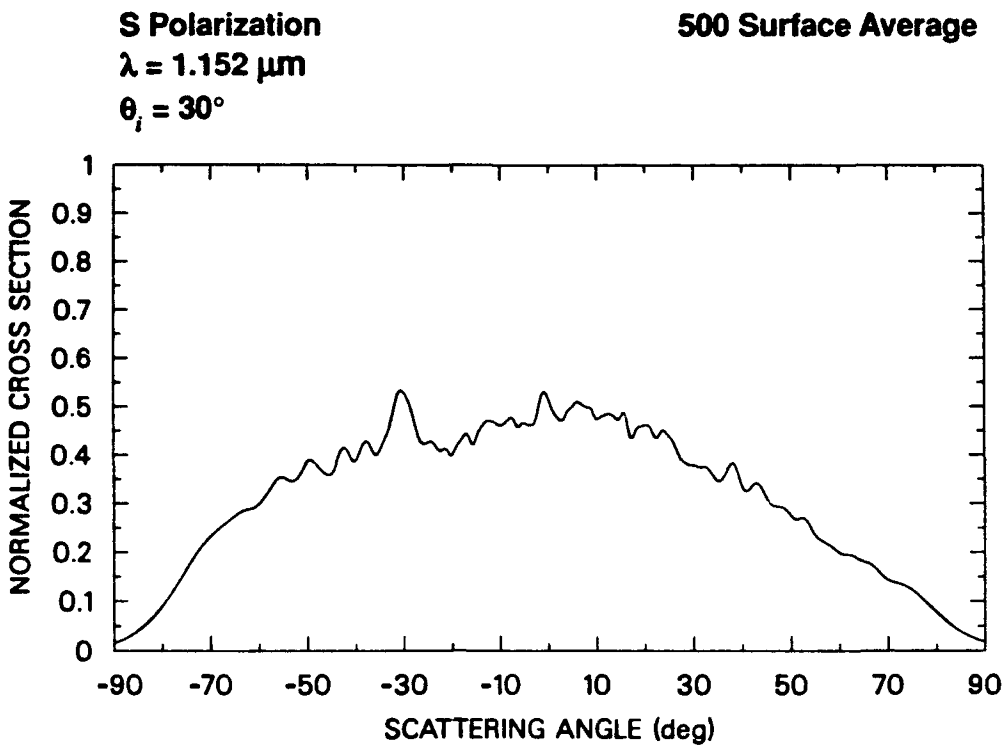

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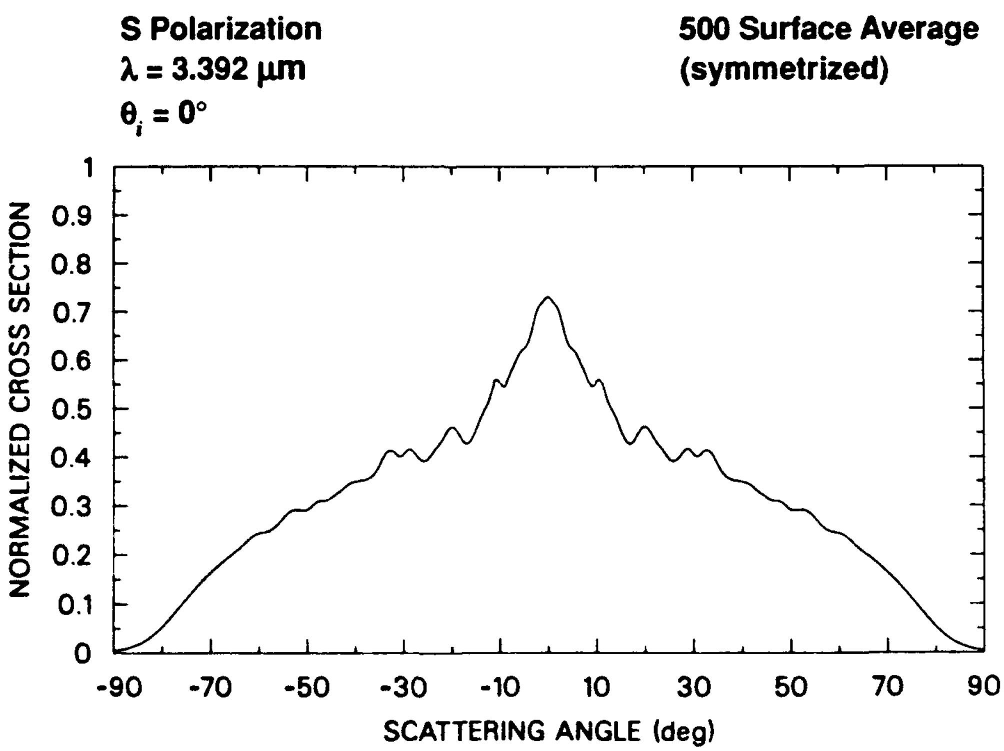

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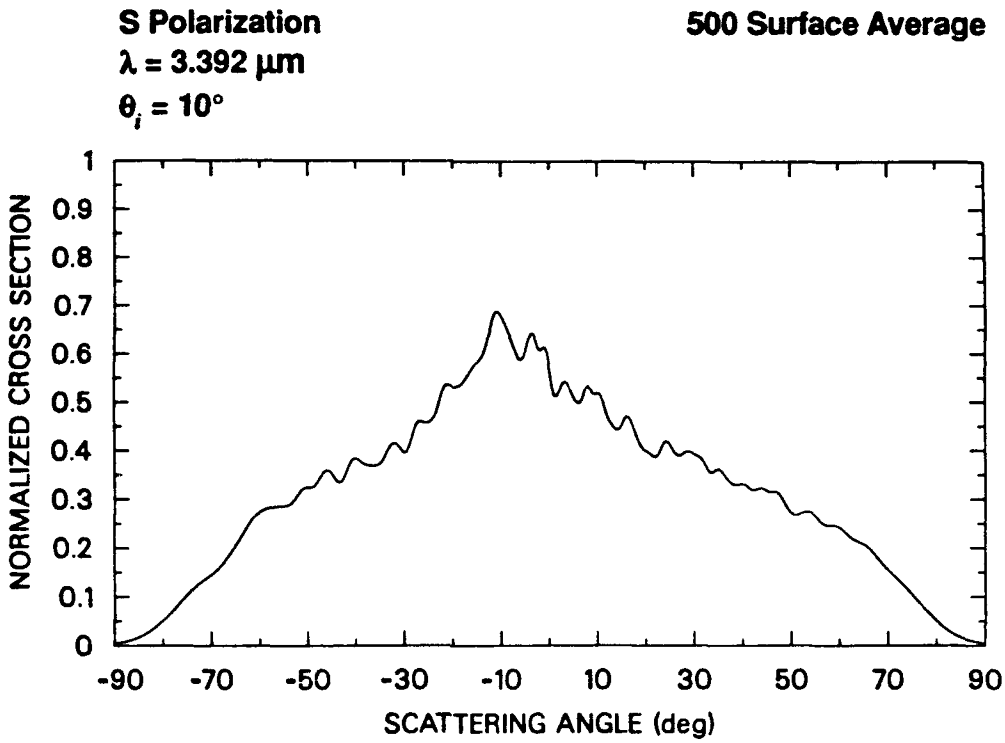

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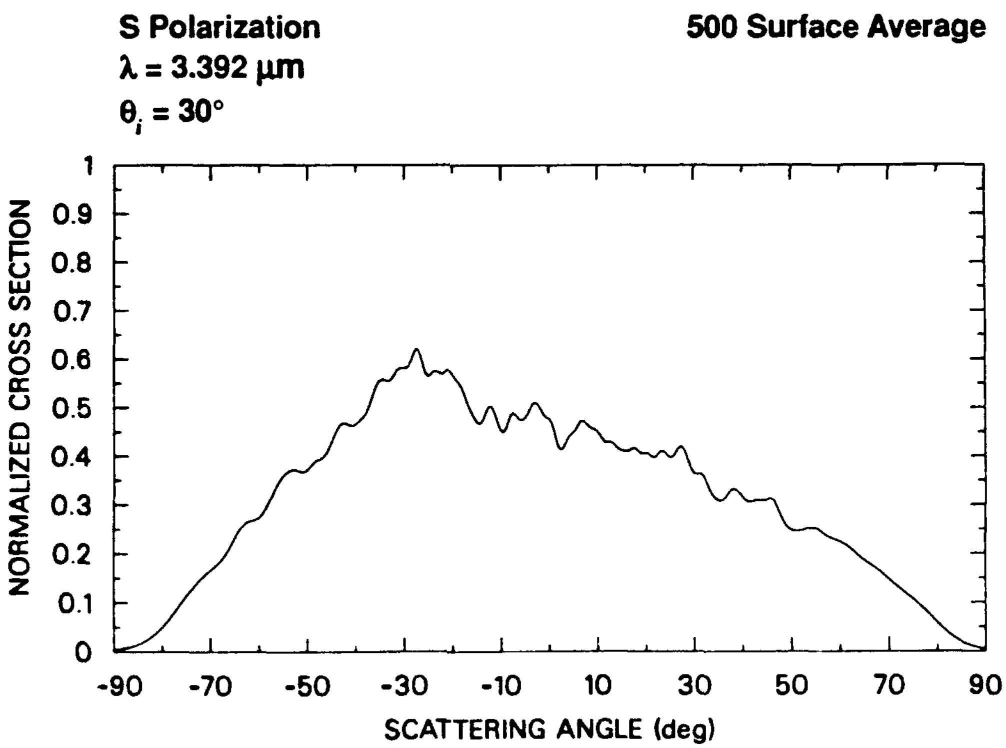

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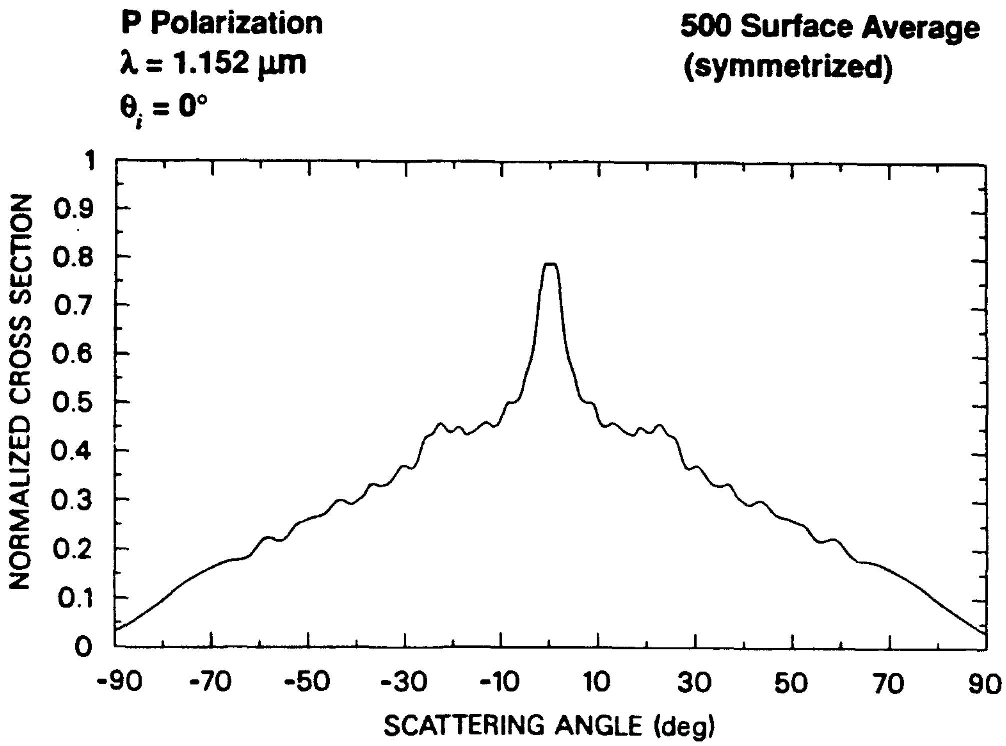

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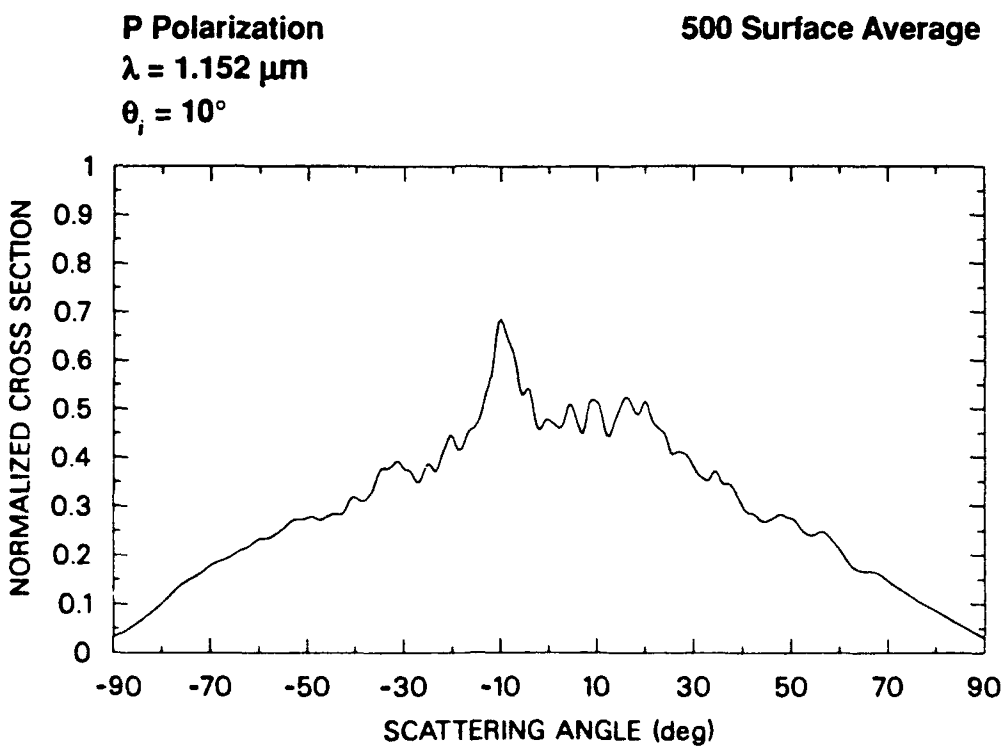

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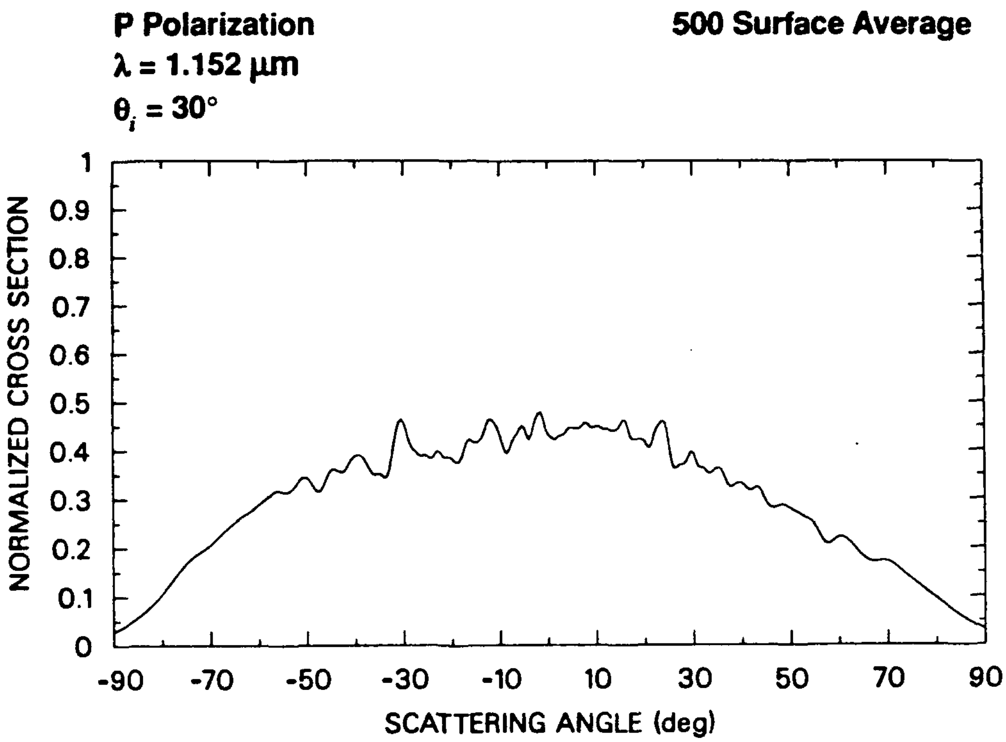

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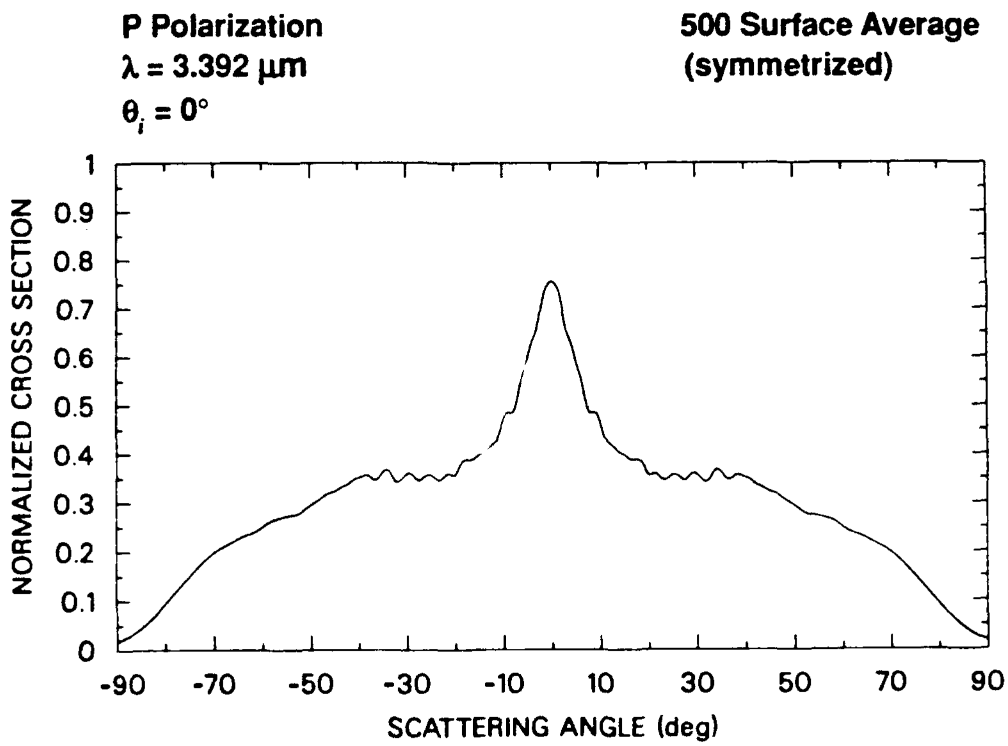

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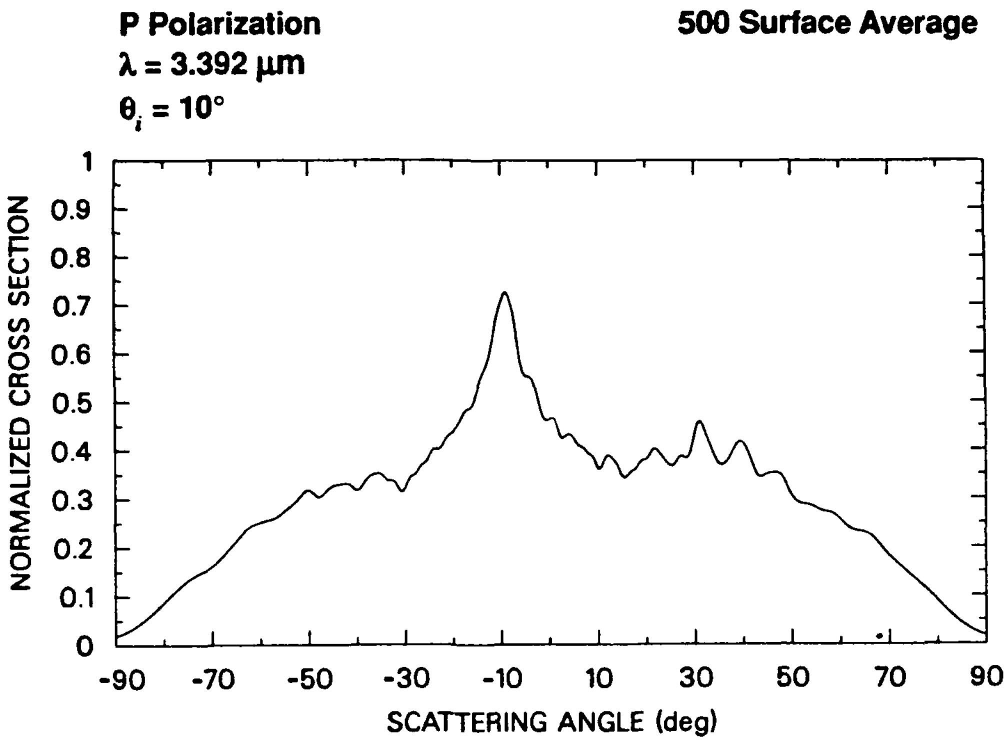

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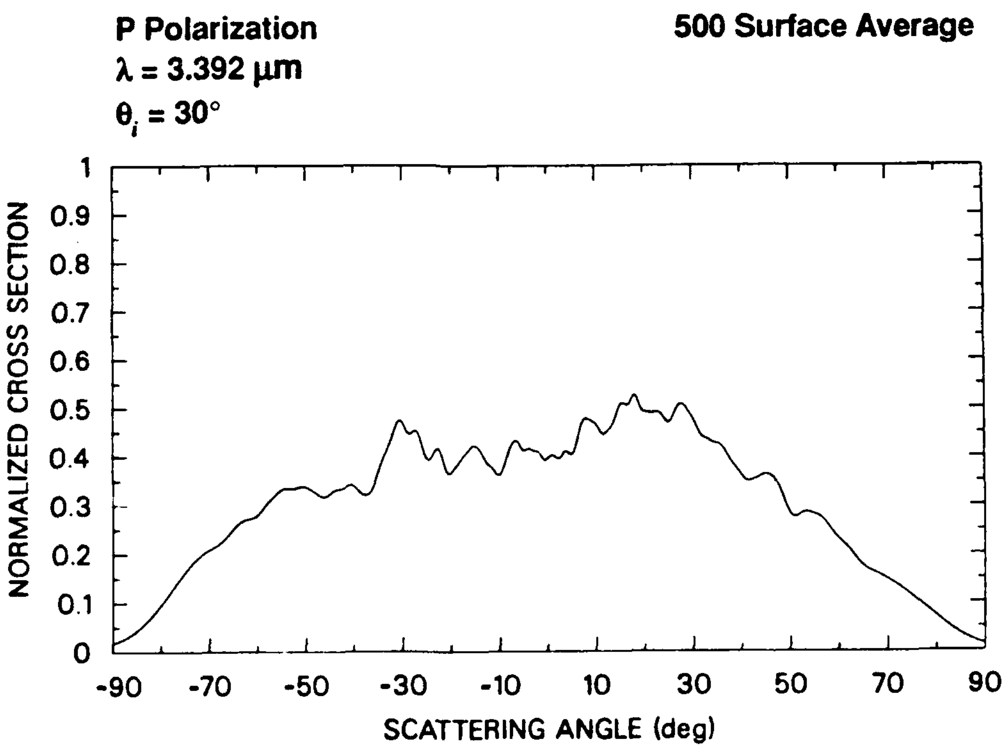

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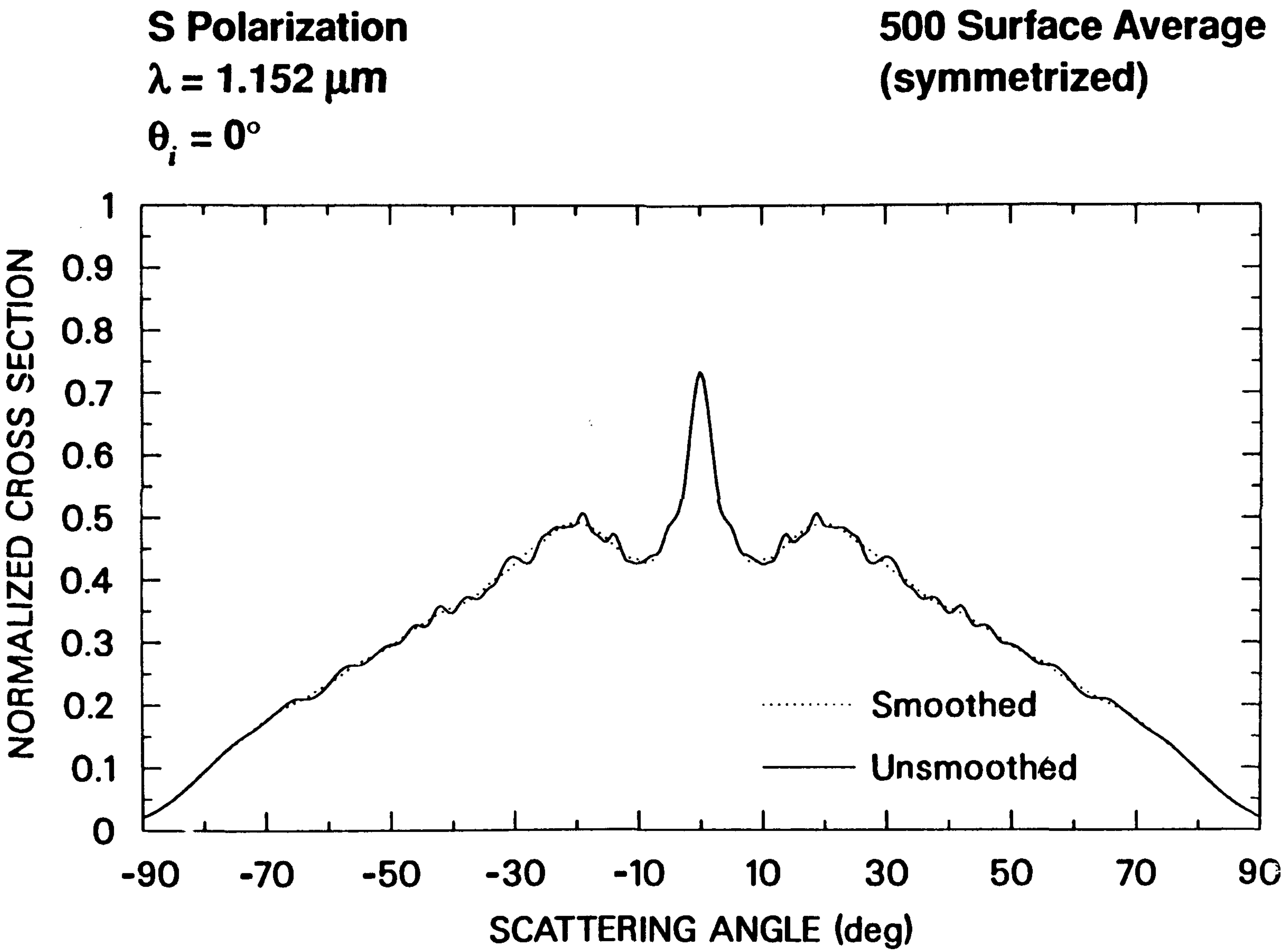
S Polarization
λ = 1.152 μm
θi = 0°
500 Surface Average
(symmetrized)
NORMALIZED CROSS SECTION
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-90
-70
-50
-30
-10
10
30
50
70
90
SCATTERING ANGLE (deg)
Smoothed
Unsmoothed

Figure 16.